Evaluation of Sockeye Salmon Smolt Population Estimate Bias

From Single-Site Mark Recapture Experiments

By

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ABSTRACT

Sockeye salmon *Oncorhynchus nerka* smolt populations are estimated in the Westward Region to assist with management of commercial fisheries. Most smolt population estimates are made using mark-recapture experiments that use a 'single-site' design. Single-site designs rely on a single trap to capture and recapture smolts: smolts are caught in a trap, transported upstream, dyed, and released into the stream. The number of recaptured marked fish caught in the trap provides an estimate of the capture probability (i.e., trap efficiency). Previous reports using this design were criticized because the fish used to test the capture probability of the trap were caught by the trap. This mark-recapture design could be a problem if the trap is selective and consistently misses a portion of the emigrating smolt population (unequal vulnerability); for example, larger smolt may be able to avoid some traps. Unequal vulnerability to the trap would cause an underestimate of the smolt population because a portion of the emigrating population is not included in the estimate. In 1996 and 1997, a mark-recapture project was implemented at Akalura Creek to estimate the sockeye salmon smolt population. A separate weir was also installed to count all of the emigrating smolts. These counts were compared to the mark-recapture estimate. Handling mortality was recorded during the mark-recapture experiments. A second set of experiments was performed to estimate the delayed mortality of marked smolts. In 1996 and 1997, smolt population estimates, based on mark-recapture experiments, were larger than the counts from the weir. These overestimates of the smolt populations suggest that the original criticism of unequal vulnerability was incorrect. The most apparent problem associated with the mark-recapture experiments was the large proportion of marks that were never recovered at the trap or weir even after accounting for delayed mortality. Lost marks cause an underestimate of the capture probability and an overestimate of the smolt population. In 1996, the estimate was 24% (272,632; 95% C.I. 243,584 – 301,680) higher than the weir count (201,437). In 1997, the estimate was 4% (201,054; 95% C.I. 182,795 – 219,312) higher than the weir count 193,064.

INTRODUCTION

Sockeye salmon *Oncorhynchus nerka* have been documented in 39 systems within the Kodiak Management Area (KMA; Brennan 2001). Sockeye salmon runs support large commercial, sport, and subsistence fisheries within the KMA, with commercial exvessel values averaging 18.8 million dollars (Brennan 2001).

Population estimates of sockeye salmon smolts are an important component for managing fisheries. Abundance estimates of the smolting cohort aid in forecasting recruitment to the commercial fishery (Paulus and Parker 1974; Crawford and Cross 1992). Smolt estimates are also used to assess marine survival (Koenings et al. 1993) and to develop escapement goals (Kyle et al. 1988; Coggins and Sagalkin 1998).

In order to estimate the abundance of smolts, they have to be captured during their emigration and the proportion captured has be known or estimated. Smolts are difficult to capture because they migrate in large numbers at night during the spring when high, variable stream flows from spring snowmelt can be problematic for traps. Methods used to capture smolts include trapping with fyke nets, weirs (Coggins and Sagalkin 1998), counting fences (Dempson and Stansbury 1991), screw traps (Kennen et al. 1994; Thedinga et al. 1994), incline plane traps (Seelbach et al. 1984; Dubois et al. 1991; Todd 1994), and Canadian fan traps (Ginetz 1977). Smolt population estimates have been generated using methods that do not require smolt capture; for example, hydroacoustics (Moore and Potter 1994) and camera observations (Cousens et al. 1982). However, for most systems in the KMA population estimates require mark-recapture techniques to estimate capture probability (Sagalkin 1999; Whalen et al. 1999) due to high smolt abundance and remote locations (logistical problems e.g., power supply for cameras).

In the KMA, sockeye salmon smolt enumeration projects have been conducted by the Alaska Department of Fish and Game (ADF&G) at the outlet creeks of Spiridon (Honnold 1997), Malina (Schrof et al. 2000), Frazer (Sagalkin 1999), Akalura (Coggins and Sagalkin 1999), Red (Coggins 1997), Olga (Barrett et al. 1993a,b), and Karluk Lakes (Schrof et al. 2000). The majority of these projects relied on mark-recapture techniques to estimate the capture probability of the trap, which was used to estimate the total emigrating smolt population. The capture probability was estimated using a derivative of the Chapman Modification (Chapman 1951; Ricker 1975; Carlson et al. 1998).

Problems inherent in various capture methods for smolts include variability in gear efficiency at high and low flows, debris loading of nets and screens, trap avoidance by smolts (King et al. 1994 a,b), and mortality associated with handling stress and gear design (Seber 1982). ADF&G projects in the KMA rely on a single capture-recapture site design described by Carlson et al. (1998). A portion of the emigrating smolts are caught in a trap, transported upstream, marked with dye, and released into the stream. Recaptured marked fish are counted at the trap and released downstream. Marking events are repeated (stratified by time periods) throughout the season. The recovery rate of marked smolts and the total number of downstream captures in each stratum are used to estimate the size of the smolt population emigrating during each time period (Carlson et al. 1998). The total smolt population is then estimated by summing across strata.

Single-site methods are preferred because they (1) reduce handling of smolt compared to multiple capture events, (2) only require maintenance and operation of one trap, and (3) require fewer personnel. Stratification by time periods is intended to account for differences in catchability of smolt among strata due to changes in river conditions or smolt behavior.

A review of a mark-recapture project at Akalura Lake (Coggins and Sagalkin 1998) suggested that some methods may have resulted in biased estimates (Appendix A). The reviewer argued that "the vulnerability of the population at large to the trap cannot be determined by this method [single capture-recapture site] " because the fish used to test the efficiency of the trap were previously caught by the trap. If there was a segment of the population that was avoiding a trap, then the estimates would be biased.

The objectives of this study were to (1) count emigrating sockeye salmon smolt through a weir; (2) estimate emigrating sockeye salmon smolt using capture probabilities and the single capture-recapture design; and (3) compare numbers of sockeye salmon smolt counted from the weir to estimates calculated from the mark-recapture experiment. The purpose of this report is to identify whether biases exist in the mark-recapture estimates and the direction of the bias.

METHODS

Description of Study Area

Akalura Lake (57° 11' N lat.; 154° 15' W long.) is located 1.6 km south of Red Lake on Kodiak Island (Figure 1). The lake is composed of a north-south arm, 3.2 km long, 1.2 wide, and an east-west arm 4.0 km long and 0.8 km wide. The lake surface area is 4.9 km^2, and the lake has a mean depth of 9.9 m (Honnold 1993; Schrof et al. 2000).

Overview of Sampling Design

From 1996 to 1997, smolts were caught using two Canadian fan traps (Figure 2). The first trap (Trap A) was oriented close to the east stream bank with wings at 30^o angles extending outward from the mouth of the trap. The east wing extended to the shoreline. The outer edge of the east wing to the outer edge of the west wing spanned 2.9 m. The second trap (Trap B) was close to the center of the channel and downstream from Trap A. Trap B's east wing extended to the tip of the west wing of Trap A (forming an inverted 'V'). The west wing of Trap B extended to the west shoreline. In 1997, the design was modified slightly: rather than the wings from the two traps touching, the east wing from Trap B connected to the back of Trap A.

Trap A and Trap B together blocked the entire stream and are referred to as the 'smolt-weir'. Counts from the smolt-weir were considered total counts. Capture probability was estimated for Trap A using mark-recapture experiments. Trap B sampled a larger portion of the stream (~68%) than Trap A.

Mark-recapture experiments were repeated throughout the smolt emigration to account for temporal differences (stratification). Generally, mark-recapture experiments were repeated weekly, thus each stratum is approximately one week.

Smolt Enumeration

Trap live boxes were inspected approximately every 30 min from 2130 hours to 0530 hours daily. Light sources were battery headlamps. Fish caught in the trap were identified using external characteristics (McConnell and Snyder 1972). When trap catches were less than 100 fish per 30-min interval, the live box was inspected about once per hour (Barrett et al. 1993a, b). On some nights, the number of smolts captured was too large to count each smolt without the live box becoming overcrowded. In these situations the crew used a catch-weight method to estimate the number of smolts captured. First, a sample was taken to determine species count by weight; this involved counting the number of fish by species from a known aggregate weight obtained using a hanging scale. Every 10^{th} aggregate weight was sampled for species composition. If the catch-weight method was required during a mark-recapture experiment all smolts were examined for marks as they were poured into the catch-weight hanging scale.

Handling and Delayed Mortality

In 1996 and 1997, smolt mortality was recorded during transport, transport recovery, dyeing, dye recovery, and the stream release stages of the project. For this study, "handling mortality" is defined as smolt mortality that occurred during the marking process; this mortality was directly measurable. In contrast, "delayed mortality" is defined as the number of smolts that perished after they were released back into the stream after being marked; this mortality was estimated using the following experiment.

In 1996, 300 additional smolts were transported during each of the four mark-recapture experiments to evaluate delayed mortality. Half of the 300 held smolts (n=150) were marked and half (n=150) were left unmarked; all 300 smolts were held in a perforated live box and monitored for five days for mortalities. This experiment was used to evaluate whether the transport and/or the dye caused delayed smolt mortality. Differential mortality between marked and unmarked smolt was tested in 1996 using a one tailed t-test at α=0.05 (Dowdy and Wearden 1991).

In 1997, the delayed mortality experiment was modified. Approximately 100 of the smolts that were transported and marked for the mark-recapture experiment were retained; no unmarked smolts were held. Smolts were retained for five days to monitor delayed mortality.

In 1997, delayed mortality estimates were used to adjust the number of marked fish released to account for unobserved mortality. These adjustments were not made in 1996 because delayed mortality experiments were not done during every mark-recapture event.

Estimating Capture Probability

The probability of smolt capture for Trap A was estimated on a weekly basis. Approximately 500 smolts caught in Trap A were retained, transported 1 km upstream from the trap, dyed using Bismark Brown Y dye, and released into a low velocity part of the stream (<0.5 m/sec; Barrett et al. 1993a, b; Swanton et al. 1995; Swanton et al. 1996; Coggins and Sagalkin 1998). The mark-recapture experiments were scheduled so that the release time was at approximately 2200 hours, coinciding with 'natural' migratory timing. Following the release of marked fish, the smolt-weir was checked for recoveries for a minimum of four days. Marked smolts that were recovered from Trap A were used to estimate the capture probability of Trap A. The capture probability was calculated (Ricker 1975) as:

$$u = \frac{m_h}{M_h} \tag{1}$$

and the variance as:

$$V(u) = \frac{m_h\left(C - M_h\right)}{M_h^2 C} \tag{2}$$

where

u	=	rate of exploitation of the population
h	=	stratum (usually 4 throughout the season)
M_h	=	number of marked smolts released in stratum h
m_h	=	number of marked smolts recaptured in h
C	=	sum of trap catch in stratum h.

The daily *true capture probability* of Trap A was calculated as the proportion of the daily number of smolts caught in Trap A compared to the daily number of smolts caught in the smolt-weir (i.e., sum of Trap A and Trap B). The true capture probability for each stratum was then calculated as the average of the daily actual capture probabilities (sum of Trap A/(sum of Trap A&B)) in that stratum. The true capture probability of the trap was then compared to the estimated capture probability of the trap to determine if there were biases in the estimate.

We estimated mark loss by counting total recaptured smolts from the weir. The difference between recaptured smolts from the weir and the number released was an estimate of total mortality of marked fish (handling and predator). We assumed the difference between the estimated delayed mortality and the total mortality were marked fish that were overlooked or lost to predation.

Population Estimates

The smolt population was estimated using the capture probability of Trap A and the following estimator:

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1} \tag{3}$$

where

h	=	stratum (usually 4 throughout the season)
U_h	=	total smolt population size in h, minus observed mortality
u_h	=	the number of unmarked smolts recaptured in h
M_h	=	number of marked smolts released in stratum h
m_h	=	number of marked smolts recaptured in h

The population estimate was then compared against the total count obtained from the smolt-weir.

Correlation

In addition to the basic comparison described above (i.e., comparing estimates versus knowns), Pearson correlation (Dowdy and Wearden 1991) coefficients were calculated for catch, capture probability, and mortality with other measured variables (e.g., temperature). This analysis was used to explore causal relationships. We used a correlation coefficient (r) of 0.75 as our criteria for whether a relationship existed between two variables.

RESULTS

Handling and Delayed Mortality

In 1996 and 1997, very few smolts were lost from handling mortality, except 24 May 1996 and June 5, 1997 when more than 10 smolts died (Table 1). In both cases, additional stresses were attributed to the losses. During the 1996 test, too much dye was used, and in 1997, the supplemental oxygen ran out during the dyeing process.

Delayed mortality results in 1996 were variable, but marked fish had higher morality than unmarked fish (Table 2). High mortalities occurred on 28 May coinciding with the 24 May mark-recapture experiment, where 72 marked smolts died, but only 16 of the unmarked smolts perished. Water temperatures increased throughout the season; however, correlation between delayed mortality and water temperatures for either marked or unmarked smolts was low (Table 3). While marked smolts suffered much higher mortality than unmarked smolts, there was no significant difference (P=0.10; Table 4) between the two.

Delayed mortality ranged from zero to six fish in 1997 (Table 2). The observed condition of the smolt upon release was an indicator of potential smolt mortality – stressed fish were more sluggish upon release and resulted in more mortalities in the first experiment. The correlation between delayed mortality and water temperature was very low (Table 3).

Capture Probability

In 1996, estimated capture probabilities ranged from 6% (stratum 3) to 29% (stratum 1; Table 5). The true capture probabilities ranged from 11% (stratum 3) to 37% (stratum 4). True capture probabilities were outside the 95% confidence interval of the estimated capture probabilities.

In 1997, after trap modification, estimated capture probabilities ranged from 6% (stratum 5) to 21% (stratum 1; Table 5). The true capture probabilities ranged from 18% (stratum 5) to 24% (stratum 3). In 1997, three out of five strata had correctly estimated capture probabilities. The capture probability in strata 5 was substantially lower compared to the true capture probability; however, the smolt emigration during this time period was less than one percent of the total smolt emigration.
In 1996 there was a strong correlation between the trap catch (Trap A) and the estimated capture probability ($r = 0.77$; Table 3 and Figure 3). However, there was a very low correlation between the estimated capture probability and the true capture probability ($r = -0.03$; Figure 4), and the true capture probability and the trap catch of Trap A ($r = -0.2$; Figure 5).

In 1997, the catch was weakly correlated to the estimated capture probability ($r = 0.34$; Figure 3). However, estimated capture probability was moderately correlated to the true capture probability ($r = 0.5$) and stream height ($r = 0.54$; Table 3 and Figures 4 and 5).

There was a discrepancy in most strata between the total number of marked fish released and the total number counted through the smolt-weir in 1996 and 1997 (Table 6); however, there was not a relationship ($r < 0.75$) between missed marks and smolt-weir counts (Figure 6).

Population Estimates

Similar patterns of catch occurred for Trap A as Trap B in 1996 and 1997; however, the pattern of catch between the two traps was more similar in 1997 than in 1996 (Figure 7). The estimated smolt emigration in 1996 was 272,632 (95% C.I. 243,584 – 301,680) during the period when the trap was in place compared to 201,437 counted through the smolt-weir during this period (Table 7). The difference between the estimate and the actual population abundance (62,101) was a 24% discrepancy. The estimated smolt emigration in 1997 was 206,453 before correcting for delayed mortality. Correcting for delayed mortality resulted in a smolt emigration estimate of 201,054 (95% C.I. 182,795 – 219,312) during the period when the trap was in place compared to 193,064 counted through the smolt-weir during this period. The difference between the estimate and the actual (7,990) was a 4% discrepancy.

In 1996, mark-recapture methods underestimated the population (overestimating the capture probability) of the trap in the first stratum; however, overestimated the population in the remaining strata (2-6; Figure 8). The smolt population was estimated more accurately in 1997 than in 1996, and the weir count was contained within the 95% C.I. of the estimate. The population was estimated very close to the actual population in all strata except the second stratum. The first part of the second stratum was overestimated and the second half of the stratum was underestimated.

DISCUSSION

The smolt population estimate in 1996 overestimated the smolt count through the smolt-weir, while the 1997 estimate was reasonably accurate (i.e., within the 95% C.I.; Table 7). Both point estimates were higher than the true count. Overestimating the population was a result of underestimating the capture probability. It is unlikely that there was unequal vulnerability of fish to the trap because that would have resulted in an overestimate of the capture probability and an underestimate of the population (White et al. 1982). It is unlikely that our estimates are biased due to unequal vulnerability of fish of different sizes.

An underestimate of the capture probability can be caused by incomplete checking for marks, missing marks, and/or differential mortality of marked and unmarked fish (Ricker 1975). Incomplete checking for marks is usually a problem when the experiment relies on commercial or sport fisherman to report tags (Paulik 1963). However, in this application the bias caused by incomplete reporting of marks would be similar to the bias resulting from faded dye (i.e., tag loss) or from not observing marks during high emigration nights. Loss of tags (or marks) is a common problem in mark-recapture studies and is usually solved through multiple markings (Hubert et al. 1976; Seber 1982). While we did not use multiple marks, we were able to observe the visibility of marked fish held during the delayed mortality experiments. No comments were made by field personnel that would indicate that marks were not visible. Secondly, we felt that if marks were missed at the trap, they would be more likely to be missed during high emigration nights. There was no correlation between trap catch and missed marks by strata; however, the lack of relationship was caused by three observations (Figure 6). We did not know how to account for the three points confounding the relationship so we did not remove them. While we did not find a relationship between missed marks and the number of fish counted at the weir or trap, we do believe this to be a source of error, and that other factors add to this error confounding the relationship.

Differential mortality was examined in several different ways. First, in 1996, handling mortality experiments demonstrated no significant difference between marked and unmarked smolts (Table 4). Second, we corrected for delayed mortality by subtracting mortalities from the total releases (Table 6). Despite these corrections there was still a large number of marked smolts that were not accounted for at the smolt-weir (Table 6). Thus, the delayed mortality was underestimated or another source of error exists.

We have no reason to believe that our delayed mortality experiments were flawed. The only other possible source of error is through differential predation. Predation is difficult to evaluate because it is dependent on many different variables: density of predators and smolt, and smolt movement (i.e., daytime versus night). Predation makes estimation difficult because if it is equal between marked and unmarked fish then it doesn't need to be considered in the model; however, if predation is unequal between marked and unmarked fish than it may cause a bias in the estimate.

Despite the biases in the 1996 and 1997 estimates, both estimates were relatively close to the actual count. Krebs (1989) listed four recommendations for mark-recapture experiments: "1) evaluate your objectives before starting, and do not assume that mark-recapture methods are the easiest path to valid population estimates, 2) pick your mark-recapture method before starting field work, and build into your sampling program a test of the model's assumptions, 3) treat all population estimates and confidence intervals with caution and recheck your assumptions often, and 4) if you identify sources of error, recognize that the resulting estimates are biased. Biased estimates may be better than no estimates, but you should be careful to use these estimates only as indices of population size. If the bias is consistent, your biased estimates may be a reliable indicator of changes in the population".

SUMMARY AND CONCLUSIONS

The 1996 confidence interval (95%) of the smolt population generated by the mark-recapture experiment was 24% higher than the actual smolt count; however, the 1997 confidence interval of the smolt population estimate contained the actual smolt count. Point estimates for both years were high, and similar sources of error likely affected both years. Sources of error included delayed mortality, missed marks at the trap, predation, and the design of the trap. We estimated delayed mortality that occurred during the marking process. We also estimated the number of marks not recaptured through the use of a smolt-weir, but in a normal application of mark-recapture experiment this would be unknown. We were unable to estimate tag-loss from predation. We were also unable to determine what caused the difference in capture probability between 1996 and 1997 other than attributing the difference to the design of the trap and smolt-weir.

KMA mark-recapture projects utilize smolt population estimates to estimate survival rates. Often, smolt projects are not continued long enough for them to be used as appropriate indices. While most KMA smolt projects integrate experiments to test some assumptions, not all of the assumptions are evaluated.

GENERAL RECOMMENDATIONS

1. The most apparent problem with existing mark-recapture projects is the assumption that marking fish does not affect their catchability. Experiments that evaluate this assumption should be developed.

2. Delayed mortality can be a significant source of error. Experiments should be standardized and employed consistently.

3. A different type of validation project should be conducted on a large system (e.g., Karluk River) because different assumptions may be violated. A validation study on a large system will likely require a different design (e.g., sonar) than the one used at Akalura River.

4. Smolt projects increase in value with longer time series because estimates can be evaluated as indices even if consistent biases exist.

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Table 1. Akalura Lake sockeye salmon smolt mortality during four steps of the mark-recapture experiments, 1996 and 1997.

	Date	Mortality					Water Temp.	
				Dye				
	Date	Transport	Recov.	"Bath"[a]	Recov.	Total	Begin (°C)[b]	End (°C)[c]
1996								
Experiment 1	06-May	0	0	0	0	0	10	8
Experiment 2	11-May	0	0	1	2	3	14	11
Experiment 3	18-May	0	0	0	7	7	14	11
Experiment 4	24-May	0	2	17	18	37	11	10
Experiment 5	30-May	0	0	0	0	0	12	10
Experiment 6	06-Jun	0	0	0	0	0	16	13
Experiment 7	13-Jun	0	0	0	0	0	12	11
Mean		0	0	3	4	7	13	11
1997								
Experiment 1	07-May	1	1	0	2	4	9	7
Experiment 2	14-May	0	0	0	0	0	7	6
Experiment 3	22-May	1	1	2	2	6	12	10
Experiment 4	28-May	0	0	0	0	0	13	13
Experiment 5	05-Jun	1	1	0	10	12	14	13
Mean		1	1	0	3	4	11	10

[a] The dye "bath" is the portion of the dye process where the smolt are submerged in the liquid dye.

[b] Water temperature taken at the trap at the beginning of the mark-recapture experiment.

[c] Water temperature taken at the release site at the end of the mark-recapture experiment.

Table 2. Results from delayed mortality experiments conducted at Akalura Lake, 1996 and 1997.

	Begin	Number Retained		Mortalities	
	Date	Undyed	Dyed	Undyed	Dyed
1996					
Experiment 1	06-May	150	150	3 (2%)	20 (13.3%)
Experiment 2	19-May	150	150	3 (2%)	8 (5.3%)
Experiment 3	28-May	250	250	16 (16.4%)	72 (28.8%)
Experiment 4	17-Jun	225	225	3 (1.3%)	6 (2.7%)
Mean		194	194	6 (5.4%)	27 (12.5%)
1997					
Experiment 1	07-May		100		4
Experiment 2	14-May		100		0
Experiment 3	22-May		100		6
Experiment 4	28-May		100		0
Experiment 5	05-Jun		100		6
Mean			100		3.2

Table 3. Correlation coefficients for variables pertaining to the mark-recapture experiments at Akalura Lake, 1996 and 1997.

Variables	1996	1997
True : Estimated Capture Probability	-0.03	0.50
Estimated Capture Probability : Trap A Catch	0.77	0.34
True Capture Probability : Trap A Catch	-0.21	0.50
Estimated Capture Probability : Stream Height	-0.40	0.54
Delayed Mortality Dyed : Stream Temperature	-0.50	0.35
Delayed Mortality Undyed : Stream Temperature	-0.58	n.a.
Delayed Mortality Dyed : Undyed	0.98	n.a.

Table 4. T-test results of the differential mortality comparing marked to unmarked smolts, 1996.

	Dyed	*Undyed*
Mean	6.25	26.50
Variance	42.25	958.33
Observations	4.00	4.00
Pearson Correlation	0.98	
Hypothesized Mean Difference	0.00	
df	3.00	
$\alpha =$	0.05	
P(T<=t) one-tail	0.10	

Table 5. Estimated and true capture probabilities from Akalura Lake, 1996 and 1997.

	Estimated Capture Probability %			Catch	% of Total
Strata	Point	95% C.I. (+/-)	True	Trap A	by strata[a]
1996					
1	29	5	19	22,178	57
2	15	3	33	8,157	12
3	6	2	11	3,701	16
4	13	3	37	8,260	11
5	10	3	29	1,968	3
6	10	3	30	259	0
Mean	14		27	7,421	
Total				44,523	
1997					
1	21	4	22	13,244	31
2	20	4	18	15,209	41
3	17	3	24	6,811	15
4	18	4	20	3,599	9
5	6	2	18	497	1
Mean	16.4		20	7,872	
Total				39,360	

[a] Percent of the total emigration (weir count) by strata.

Table 6. Recovered marked smolt from mark-recapture experiments at Akalura Lake, 1996 and 1997.

	Released	Delayed	Adj. Release[a]	Recoveries		Released - Total Recovered[c]	
	no.	Mortality %	no.	Trap A	Smolt-Weir [b]	no.	%
1996							
Strata 1	522			150	496	26	5.0
Strata 2	518	13.0	511	79	285	226	43.6
Strata 3	484	5.0	460	29	180	280	57.9
Strata 4	525			69	375	150	28.6
Strata 5	525	29.0	373	55	302	71	13.5
Strata 6	387	0.3	375	39	170	205	53.0
1997							
Strata 1	487	4.0	468	100	344	124	26.4
Strata 2	550	0.0	550	82	370	180	32.7
Strata 3	519	6.0	488	86	358	130	26.6
Strata 4	530	0.0	530	97	461	69	13.0
Strata 5	520	6.0	489	31	169	320	65.4

[a] Release numbers were adjusted to account for the delayed mortality.

[b] The smolt-weir includes recaptures from both Trap A and Trap B.

[c] Difference between the total number of released, marked smolt (adjusted when possible) and the total number of recovered, marked smolt from the smolt-weir.

Table 7. Smolt population estimates compared to true population estimates, Akalura Lake 1996 and 1997.

Year	Population Estimate		Actual
	95% Low	95% High	
1996	243,584	301,680	201,437
1997	182,795	219,312	193,064

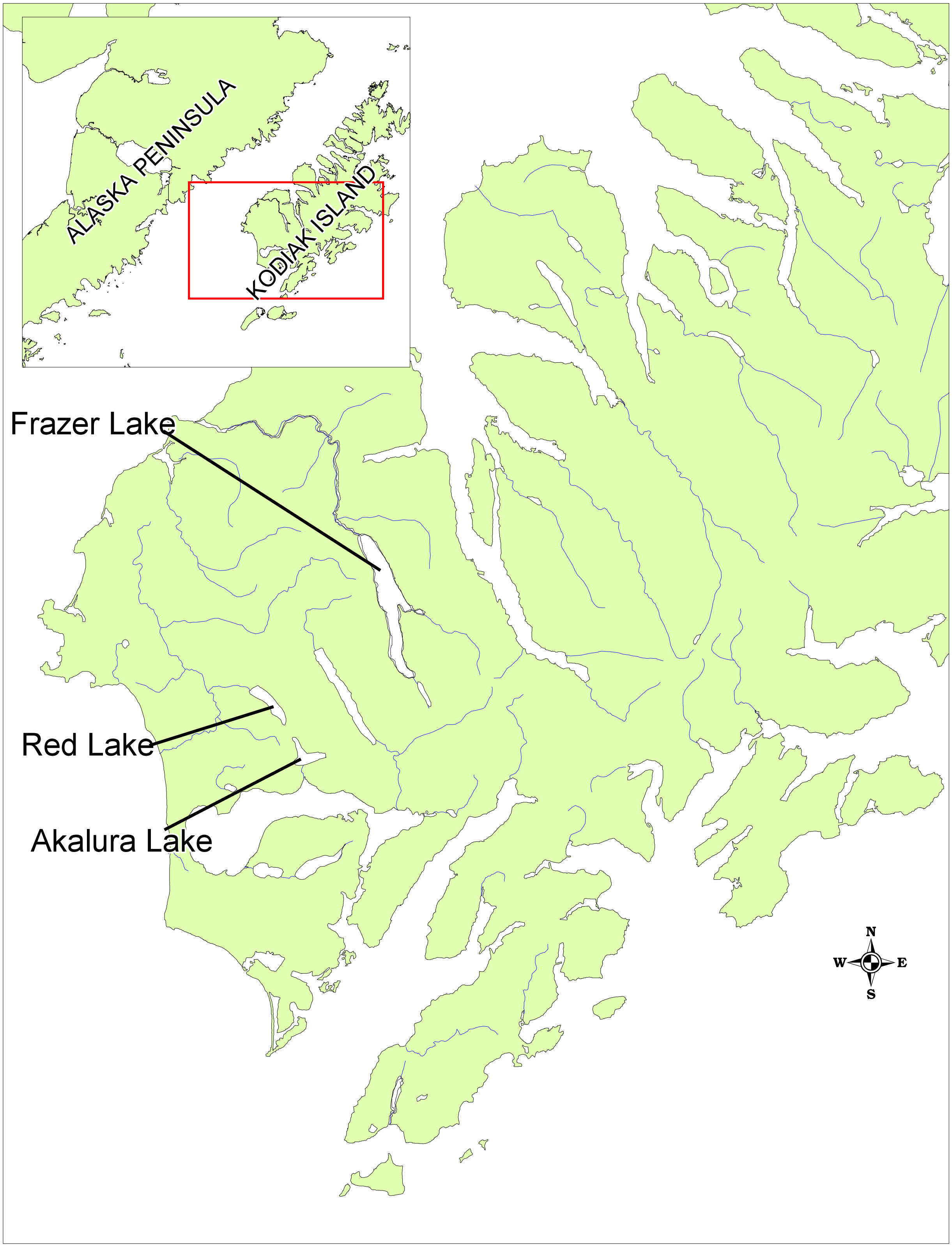


Figure 1. Akalura Lake in relation to Red and Frazer Lakes on Kodiak Island.

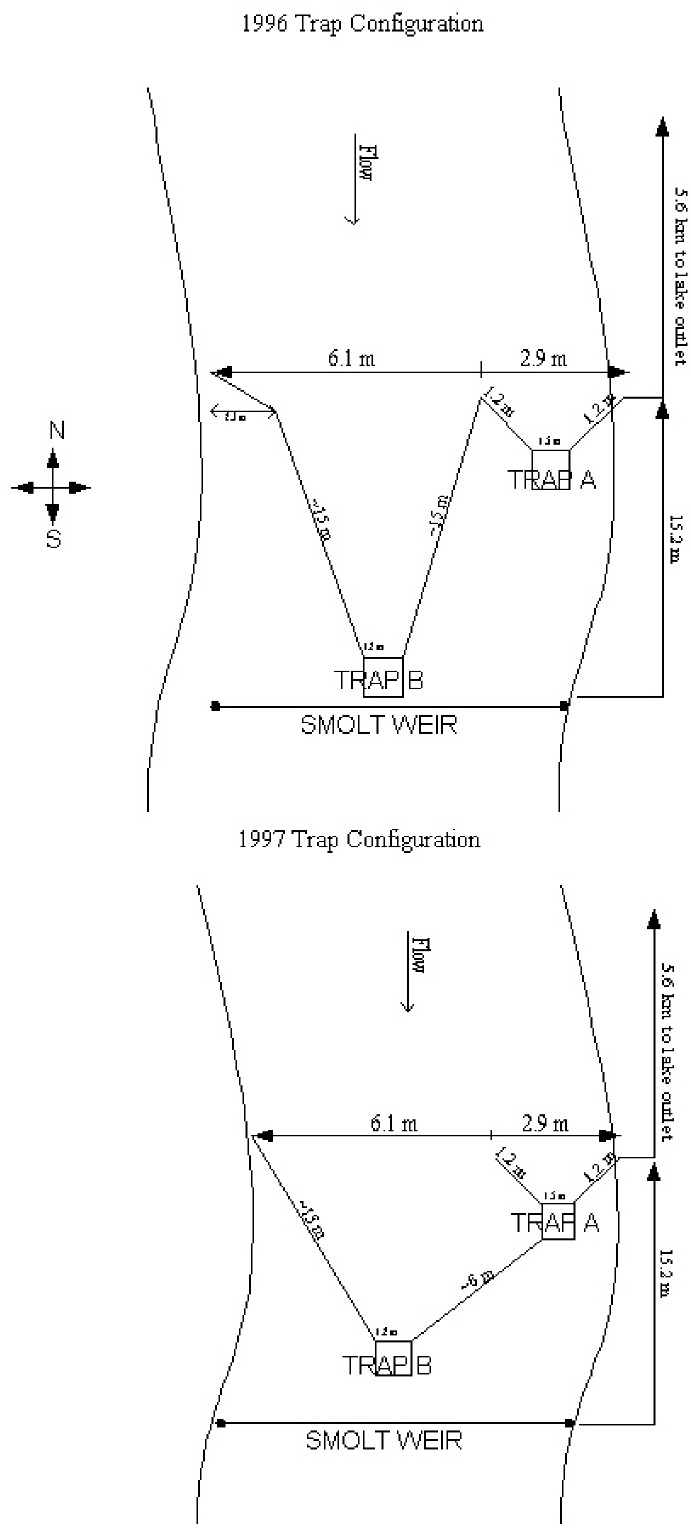
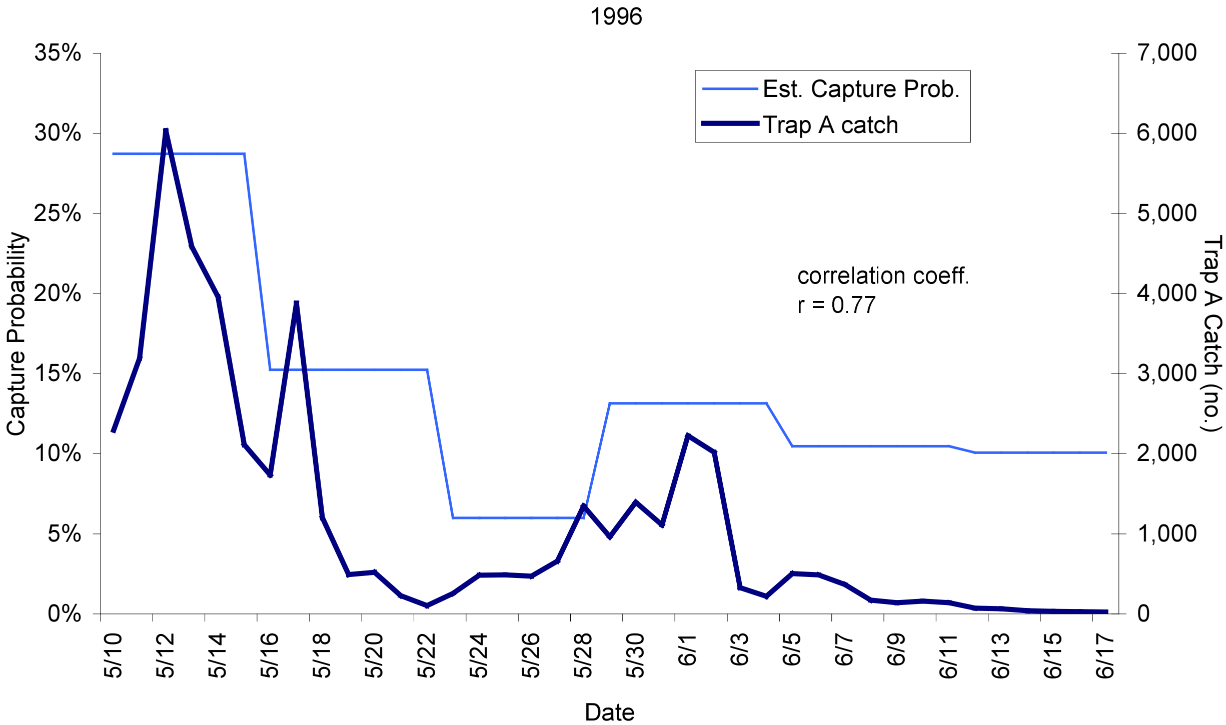


Figure 2. Trap and weir configurations at Akalura lake, 1996 and 1997.



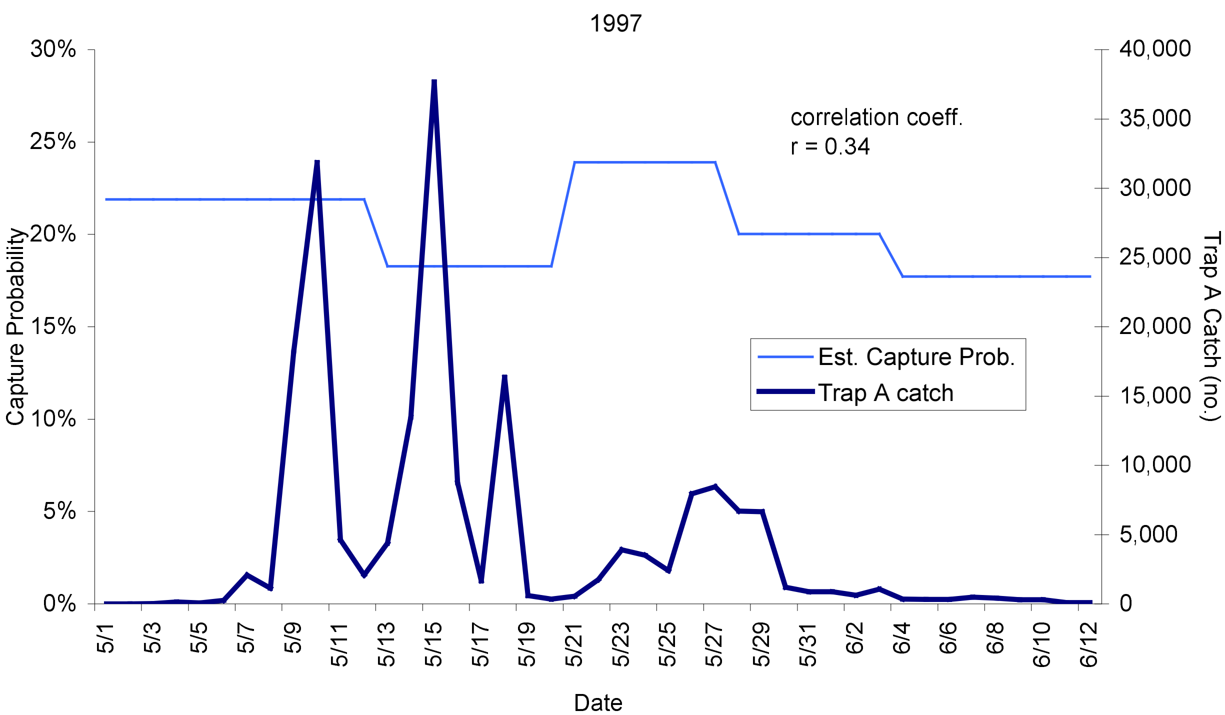


Figure 3. Estimated capture probability of smolt from Trap A compared to the catch of Trap A in 1996 and 1997 at Akalura Lake.

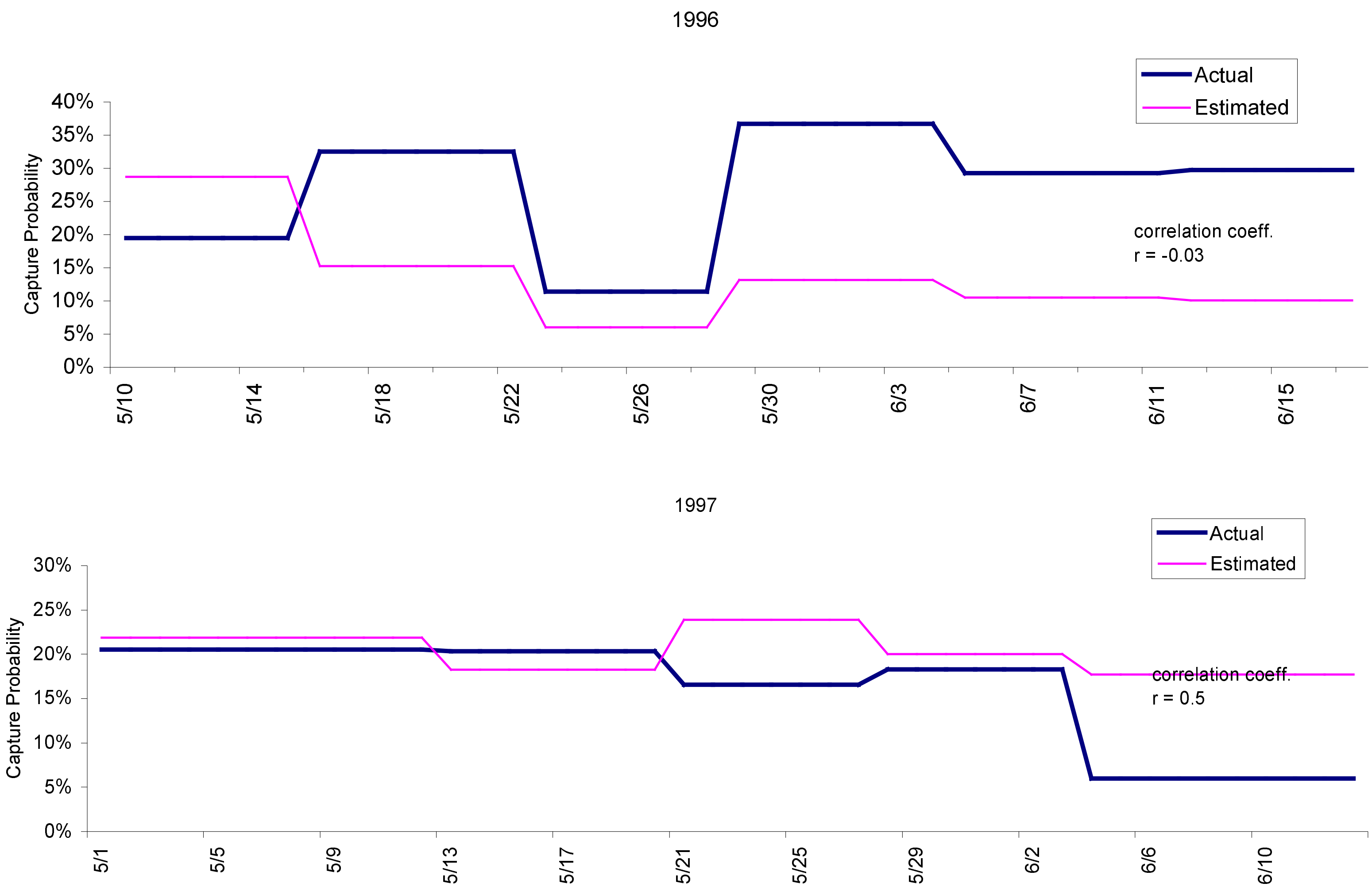
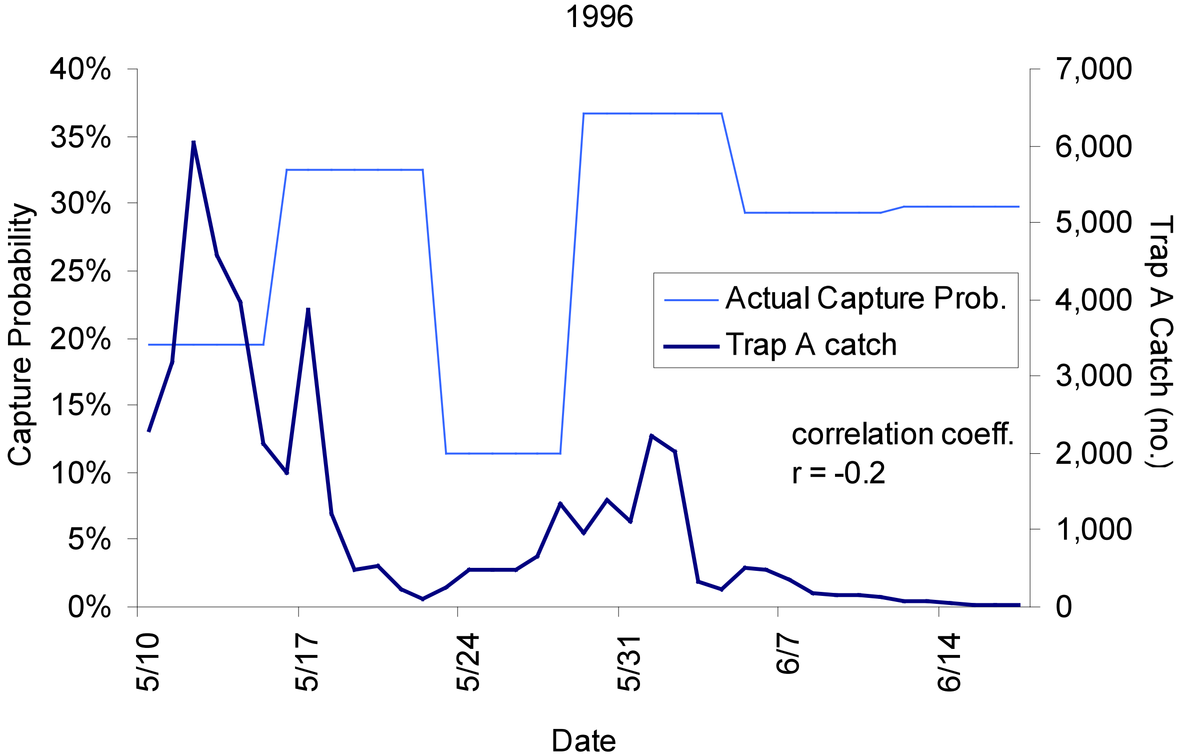


Figure 4. True and estimated capture probabilities of smolt caught from Trap A at Akalura Lake, 1996 and 1997.

NOTE: Actual capture probabilities were determined from the proportion of the daily smolt catch in Trap A versus the smolt-weir. Capture probabilities were estimated from the fraction of recovered marks in Trap A.



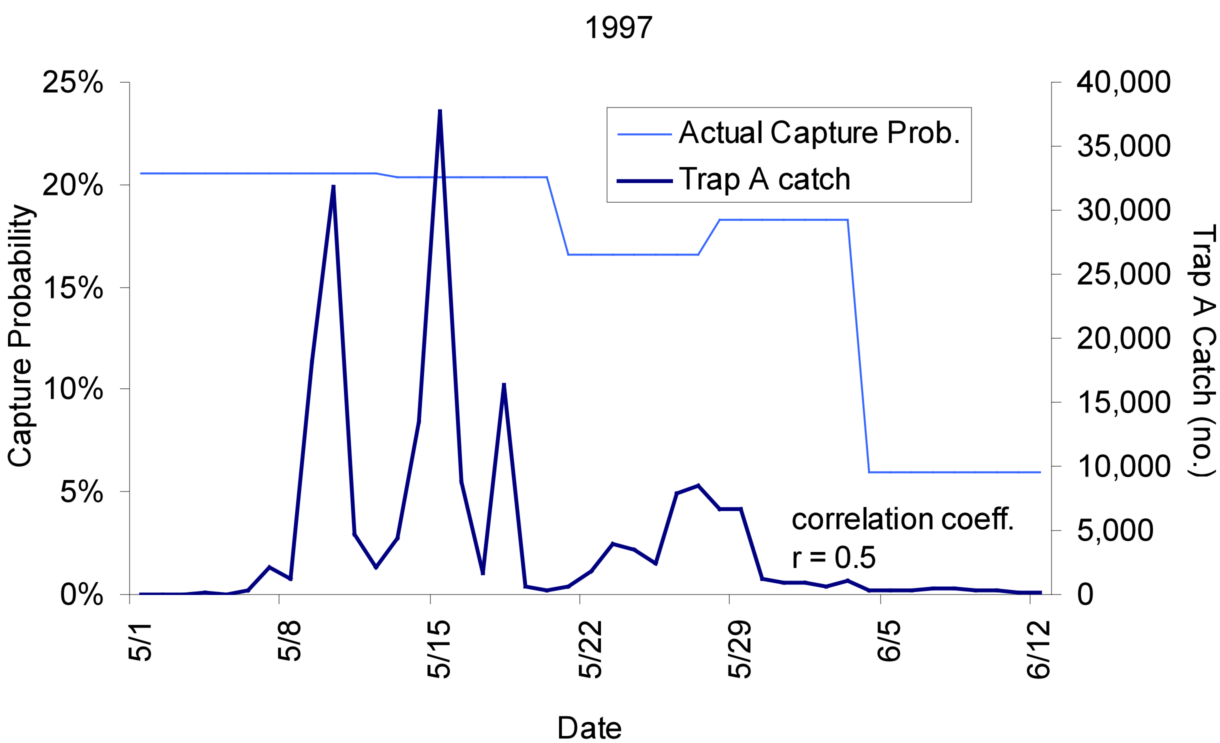


Figure 5. True probability of smolt capture at Trap A in relation to the catch at Trap A at Akalura Lake, 1996 and 1997.

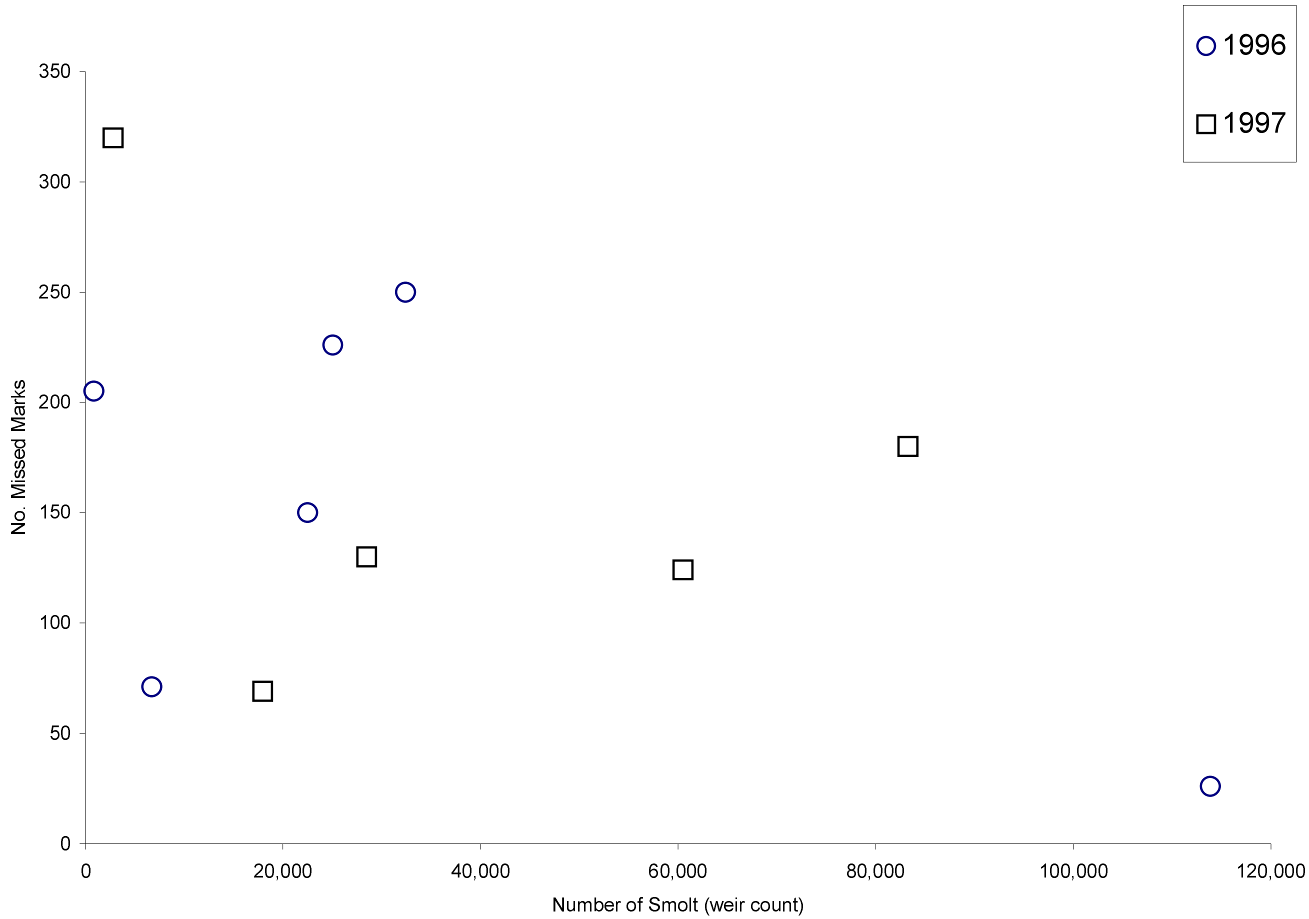
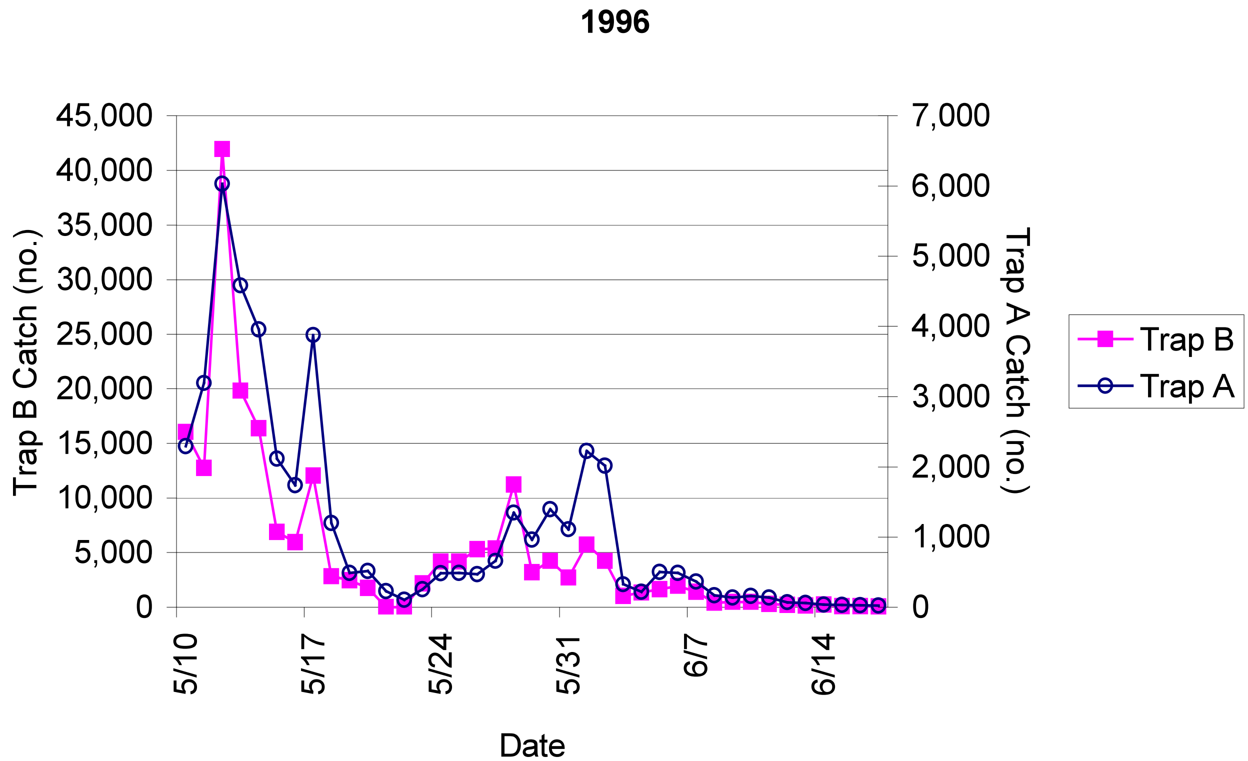


Figure 6. Number of marks missed in relation to smolt counts at the weir at Akalura Lake, 1996 and 1997.



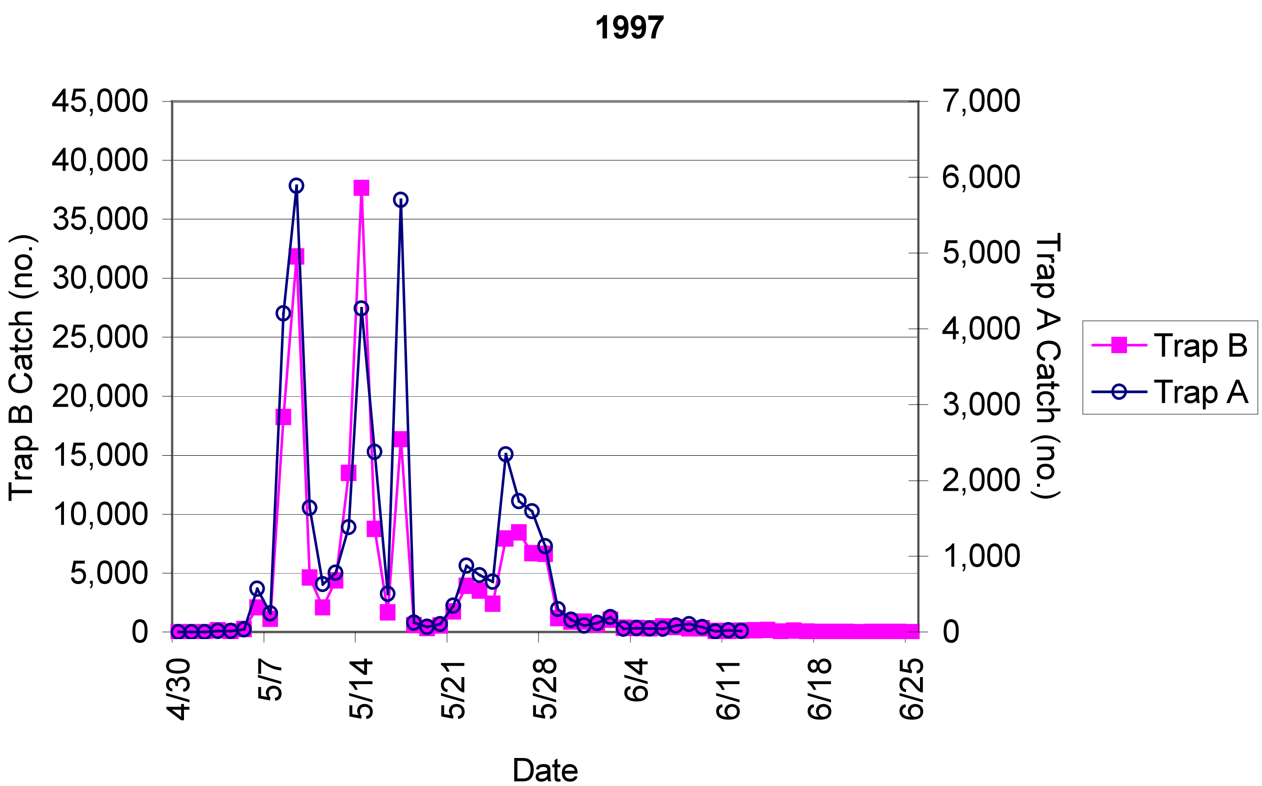


Figure 7. Trap A catch compared to Trap B catch from Akalura Lake, 1996 and 1997.

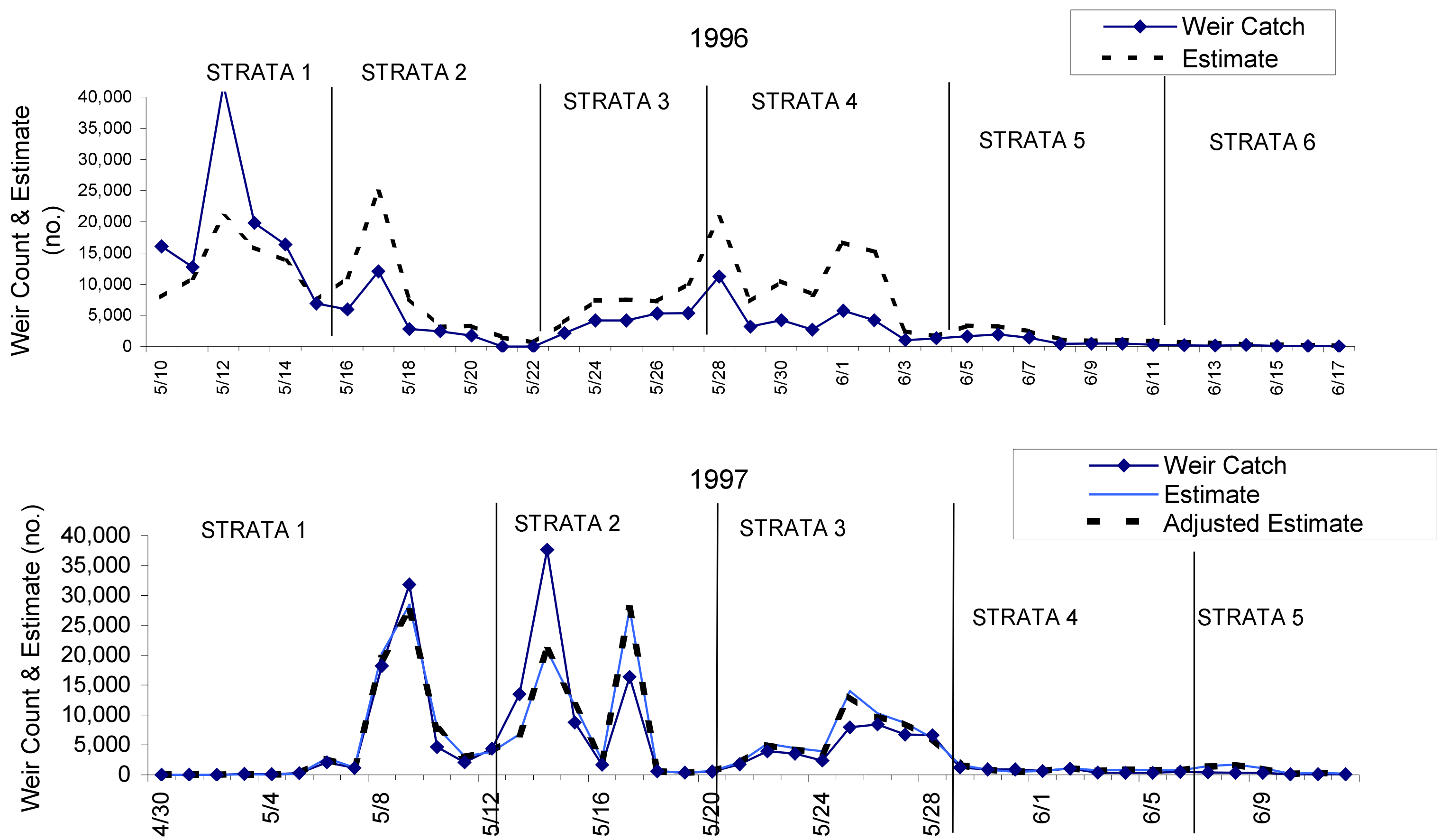


Figure 8. Smolt counted through the Akalura weir compared to the estimate (adjusted for delayed mortality) obtained from the mark-recapture experiments, 1996 and 1997.

APPENDIX

Appendix A. Reviewer's comments on the final report "Akalura Lake Sockeye Salmon Restoration", 97251-CLO.

S C I E N C E S November 3, 1998

Ms. Celia Rozen
Alaska Department of Fish and Game
Restoration Section
333 Raspberry Road
Anchorage, Alaska 99518-1599

Dear Celia,

Thank you for submission of the draft final report "Akalura Lake Sockeye salmon restoration" (97251-CLO). The reviewer was impressed with the report and the rather clear documentation of overescapement impacts to Akalura Lake and its ability to produce sockeye salmon following the oil spill. The reviewer has provided a series of constructive comments for the improvement of the report. Of particular importance is the point about smolt trap efficiencies. If the authors will address the reviewer in a revised report I will be happy to consider it at the earliest opportunity. I thank the authors and others on the ADF&G staff on Kodiak Island that contributed this study and report.

I would encourage the authors to publish their results in two manuscripts: one on testing the efficiency of the inclined plane smolt traps -- and one documenting this case study in overescapement. These would be very valuable additions to the literature on management of salmon.

Sincerely,

Robert B. Spies
Chief Scientist

cc: S. Senner
S. Schubert
L. Coggins
D. Moore

-Continued-

Citation: Coggins, L. G., Jr. and N.H. Sagalkin 1998. Akalura Lake Sockeye Salmon Restoration. *Exxon Valdez* Oil Spill Restoration Final Report (Study ID No. 97251-CLO). Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Kodiak, AK.

Recommendation

Accept with revision.

General comments

Overall the paper is in good editorial order and reasonably free of editorial errors. The authors have done a good job of investigating ways to measure the effects of overescapement, and they have questioned the critical assumptions on which their sampling program was based.

As the final report for a program of such historical importance for understanding the effects of overescapements resulting from the oil spill, it is important for this report to bring closure to the findings. The basic observation is that sockeye productivity in Akalura Lake dropped to very low levels of 1.5 – 2.3 smolts/spawner in 1989 – 1992. At the same time growth of juvenile sockeye declined, and smolt age composition shifted to older ages, consistent with the findings of slower growth. In 1991 and 1992 zooplankton biomass declined, and zooplankton size composition was consistent with heavy grazing. Due to the very low rates of sockeye productivity in the 1989 – 1992 brood years, sockeye smolt production, 1991 – 1997, and adult returns, 1994 – 1997, declined sharply.

Relatively high numbers of two-year old smolts first demonstrated evidence of recovery in 1996. The two-year olds in 1996, added to the one-year olds on 1995 and the age-zero smolt in 1994, indicated a smolt per spawner ratio of at least 9.4 resulting from the 1993 escapement. The 1994 escapement is known to have produced at least 14.2 smolts per spawner even though some of its juveniles may not have left the lake as of this 1997 study. The 1995 escapement has already been observed to produce 7.4 smolts per spawner, even though the majority of its progeny were still in Lake Akalura as of 1997.

With the trend in smolts per spawner being positive, and with the 1998 return projected to be 30,000 adults, Lake Akalura's sockeye production in support of fisheries is well on its way to recovery. Adult returns are unlikely to recover to levels that would have been produced by the escapements of 1990 – 1993 except for the oil spill overescapement event until 1999 or 2000.

The study has much to contribute in terms of methods for making smolt estimates, but its use and discussion of its data were disappointing. In particular, the study has not addressed problems inherent in using fish recovered from the smolt trap to estimate the efficiency of the smolt trap (dye marking). Such a procedure can only estimate the efficiency of the trap for the part of the population that is vulnerable to the trap in the first place. If that proportion of the population vulnerable to the trap is close to one, then using trapped fish to estimate trap efficiency would not introduce serious bias into the estimation procedure. Unfortunately it is not known what proportion is vulnerable, so the study should acknowledge this limitation.

-Continued-

Reviewer's summary of findings and objectives

The report compares findings of a final year (1997) of research on sockeye salmon *(Oncorhynchus nerka)* smolt abundance and adult returns with nine prior years of research on smolt abundance and spawning escapements and four years of limnology at Akalura Lake, Kodiak Island, Alaska. The comparison is used to draw inferences about the effects of the 1989 escapement event on productivity of sockeye populations in Akalura Lake. The report indicates that sockeye productivities in Lake Akalura were probably damaged in brood years 1989 – 1992 as a result of the 1989 overescapement. Findings and rationales are as follows.

1. One of the apparent effects of the 1989 escapement was to reduce productivities of the 1989 – 1992 sockeye brood years at Akalura to below the replacement level. The replacement level is the point at which a population goes into decline. Productivities in 1989 – 1993 ranged from 1.5 smolts per spawner (1990) to 2.3 smolts per spawner (1993). To reach the replacement level, marine survivals of smolts to adults for these brood years would have had to average 43% - 67%, or 4.3 to 6.7 times the conservative level of 10% marine mortality used by management for planning purposes. Sockeye populations that produced only 1.5 to 2.3 smolts per spawner indefinitely would certainly be extirpated in the long-term. The average rate of population loss at a productivity of 1.5 to 2.3 smolts per spawner would be 65 to 85 percent of the total population each generation.
2. The depression of sockeye productivity by the 1989 escapement was corroborated by the limnology investigations of zooplankton biomass and size composition. Although the macrozooplankton community showed no apparent response to the escapement when its juveniles reached Lake Akalura in 1990, zooplankton biomass decreased the following summer by fifty percent, and it was also lower than 1989 in 1992 (cites Edmundson et al. 1994), as the cumulative effects of the 1989 brood year and holdover production from 1988 apparently reduced the zooplankton biomass.
3. The age and size composition of the 1988 – 1992 (cites Barrett et al 1993 and data presented in this paper) provides support for the effects of the 1989 escapement. Smolts were generally smaller at age 1990 – 1992. The 1988 brood year produced some (very old) four-year old smolt, which may have been a result of slow growth due to competition with 1989 brood year production in Lake Akalura.
4. Productivity of the 1993 through 1995 (1994 are partial returns, the smolt per spawner will increase as smolts from these brood years now in the lake mature and exit are close to or above the conservative replacement level of 10 smolts per spawner.
5. In 1996 an unusually large proportion of the Akalura sockeye smolts emigrated as two year olds, leaving the 1997 emigration with no three-year olds. This indicates good growing conditions in the lake during 1995. Additional indicators of improved rearing conditions are the increasing trend in smolts per adult ratios (productivity) and increasing smolt size at age.

Specific comments

No page - Does the knowledge of interception rates of returning adults in fisheries permit an estimate of smolt to adult survival and return per spawner for 1988 – 1991? These would be important indicators if they could be calculated.

-Continued-

Multiple pages - The Houghton-Mifflin Dictionary of Science does not contain the words, "outmigrate" and "outmigration," nor are they in Webster's dictionary. In spoken language, it is convenient to use these vernacular terms because emigrate and immigrate sound the same. In written language "emigrate" and "emigration" should replace these terms.

Cover page – Wrong term, "smolt/adult production ratios" should be "smolts per adult" or "productivity." Confuses "productivity" with "production". Productivity is a rate (returns per spawner, smolts per adult) and production is the number produced.

Page 2, Introduction third paragraph first sentence, the years cited here for comparison appear to be incorrect. Check the years cited.

Page 4, Mark-recapture experiments. Dye tests used to validate trap catch efficiencies have the following problems;

a. Since the trap being tested caught the fish to be dyed, the logic is circular. Dye tests on smolts caught by the trap being tested only evaluate the trap efficiency for the population vulnerable to the trap. The vulnerability of the population at large to the trap cannot be determined by this method.
b. Without corroborative data on the size of the population entering the traps. The dye test functions only to reveal the trap efficiency for that portion of the population vulnerable to the trap The dye test begs the question of why the traps are not 100% efficient.
c. Dye experiments do not shed light on the nature of problems the trap may have. The failure of the Kenai River smolt trapping program during overescapement studies is a case in point. The trap efficiency may be less than 100 percent because the trap samples only a portion of the stream of all fish available to be caught, or because it both samples only a portion of the available population and it displays a bias toward a particular size or behavior type? In the Kenai, the trap was apparently biased toward larger smolts, and so it missed a large part of the population.

The deviations from the mean in the errors of true versus estimated trap efficiencies by stat week (Table 4) are not random – they show time trends. In trap experiments in general time trends may indicate a trend in catchability with size and or maturity. Figure 4 shows there is a time trend in age of smolt in the sampling program.

Suggest that in future the problem of estimating trap efficiency be addressed by different experimental design. The fish to be dyed should be caught by another method, say a seine, measured and then dyed, held for a while to determine mortality, and released. Comparison of the length frequency distributions of marked to recaptured would then show if the trap was biased on the size of smolt collected.

Page 5, Delayed Mortality estimation, third line from bottom first paragraph, wrong word "morality", needs "mortality"

Page 8, last paragraph. How does the 1988 brood year smolt/adult ratio compare to other Kodiak sockeye systems? Could the 1988 ratio have been depressed by the effects of the